FINAL REPORT ON 3D MODELLING OF HERCULES CC130 AIRCRAFT

FOR THE 3D DATA ACQUISITION AND MODELLING SERVICES PROJECT

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DRDC Toronto Scientific Authority
Pierre Meunier
Simulation and Modeling in Acquisition,
Rehearsal and Training (SMART) Section
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December 17, 2003

The scientific or technical validity of this Contract Report is entirely the responsibility of the contractor and the contents do not necessarily have the approval or endorsement of Defence R&D Canada.

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Author: Ray M. Obidowski Date

Project Manager: Rajesh Jha Date

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On behalf of
DEPARTMENT OF NATIONAL DEFENCE

as represented by
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Abstract

This report describes the production of three graphics models of the Hercules CC130 aircraft processed from laser scan data for both the aircraft exterior and cockpit interior. These Polygon and Non-Uniform Rational B-Spline (NURBS) surface models are scalable, and logically arranged in groups and/or layers. They also represent graphically the range of motions in the cockpit of the seats and pedals.

An external mean accuracy of less than 3 millimetres (mm), and standard error of 6-9 mm for modelled areas of interest were verified with respect to the original data. An interior mean accuracy of less than 1 mm and standard error of 2-3 mm for modelled areas of interest were similarly verified. This accuracy is consistent and compatible with the accuracy of the laser scanners and their data.

Résumé

Le présent rapport décrit la production de trois modèles graphiques de l'avion Hercules CC130 à partir de données obtenues par lecteur laser tant pour l'extérieur de l'avion que pour l'intérieur du poste de pilotage. Ces modèles de surface polygonaux et à B-spline non rationnelle uniforme (NURBS) sont vectorisés et organisés logiquement en groupes ou couches, ou les deux. Ils représentent aussi graphiquement la gamme des déplacements des sièges et des pédales dans le poste de pilotage.

Une précision moyenne à l'extérieur inférieure à 3 millimètres (mm) et un écart-type compris entre 6 et 9 mm pour les zones modélisées dignes d'intérêt ont été vérifiés par rapport aux données d'origine. Une précision moyenne à l'intérieur inférieure au millimètre et un écart-type compris entre 2 et 3 mm pour les zones modélisées dignes d'intérêt ont fait l'objet d'une vérification similaire. Cette précision correspond à la précision des lecteurs laser et de leurs données et elle est compatible avec ceux-ci.

Executive Summary

This report describes the production of three graphics models of the Hercules CC130 aircraft processed from laser scan data – the exterior, interior, and main interior pilotage objects. These Polygon and NURBS surface models are scalable, and logically arranged in groups and/or layers. They also represent graphically the range of motions in the cockpit of the pedals and seats.

An external mean accuracy of less than 3 millimetres (mm), and standard error of 6-9 mm for modelled areas of interest were verified with respect to the original data. An interior mean accuracy of less than 1 mm and standard error of 2-3 mm for modelled areas of interest were similarly verified. This is consistent and compatible with the accuracy of the laser scanners and their data. The following advanced techniques were used in the Hercules modelling:

1. Polyworks rigorous alignment and best-fit least squares transformation operations.
2. Extensive IMEdit surface reconstruction using Bezier surfaces.
3. Extensive surface filtering and smoothing operations.
4. Rhino conventional NURBS surfacing.
5. IMInspect verification of modelled surfaces and objects.
6. Polyworks semi-automated edge reconstruction.
7. Logical grouping and layering of objects and models.
8. Definition of a suitable global model coordinate system.
9. Extensive manual polygon editing and hole-filling.
10. Polyworks IMCompress polygon model compression and tolerance reduction.

The following challenges were encountered and are discussed in this report:

1. ShapeGrabber calibration related alignment errors.
2. Significant holes in coverage of cockpit interior from ShapeGrabber scanning.
3. Small areas of missing and/or noisy data in the external scans.

For future similar scanning projects the following is recommended:

1. More complete scan coverage of internal cockpit areas from more positions.
2. Video recording of measurement process for future use and archival information.
3. Exercising caution with ShapeGrabber orientation and calibration to avoid alignment errors in data.

For future modelling call-ups the following is recommended:

1. Additional liaison with Polyworks to resolve automated hole-filling difficulty.
2. Continued and additional use and training of advanced Polyworks editing tools.
3. Continued revision and service pack updates of Polyworks and Rhino.
4. More investigation and/or use of photo-texturing for control panels and consoles.
5. On-site Internet access for technical support and access to knowledge bases.

Sommaire

Le présent rapport décrit la production de trois modèles graphiques de l'avion Hercules CC130 à partir de données obtenues par lecteur laser — l'extérieur, l'intérieur et les principaux éléments de pilotage à l'intérieur. Ces modèles de surface polygonaux et à B-spline non rationnelle uniforme (NURBS) sont vectorisés et organisés logiquement en groupes ou couches, ou les deux. Ils représentent aussi graphiquement la gamme des déplacements des pédales et des sièges dans le poste de pilotage.

Une précision moyenne à l'extérieur inférieure à 3 millimètres (mm) et un écart-type compris entre 6 et 9 mm pour les zones modélisées dignes d'intérêt ont été vérifiés par rapport aux données d'origine. Une précision moyenne à l'intérieur inférieure au millimètre et un écart-type compris entre 2 et 3 mm pour les zones modélisées dignes d'intérêt ont fait l'objet d'une vérification similaire. Cette précision correspond à la précision des lecteurs laser et à leurs données et elle est compatible avec ceux-ci. Les techniques évoluées suivantes ont été utilisées pour la modélisation du Hercules :

1. opérations de transformation des moindres carrés et d'alignement rigoureux de Polyworks;
2. reconstruction poussée de surfaces IMEdit au moyen de surfaces de Bézier;
3. opérations poussées de filtrage et de lissage de surface;
4. surfaçage NURBS classique de Rhino;
5. vérification IMInspect des surfaces et des objets modélisés;
6. reconstruction semi-automatisée des arêtes de Polyworks;
7. groupage et organisation en couches logiques des objets et des modèles;
8. définition d'un système pertinent de coordonnées générales de modèle;
9. édition et remplissage manuels poussés des polygones;
10. compression de modèles de polygones par IMCompress et réduction de la tolérance.

Les défis suivants se sont présentés et sont abordés dans le rapport :

1. erreurs d'alignement liées à l'étalonnage ShapeGrabber;
2. zones manquantes importantes à l'intérieur du poste de pilotage résultant du balayage de ShapeGrabber;
3. petites zones manquantes ou données bruitées, ou les deux, dans les balayages de l'extérieur.

En vue de projets de balayage ultérieurs similaires, voici ce qui est recommandé :

1. couverture de balayage plus complète des zones à l'intérieur du poste de pilotage à partir d'un plus grand nombre de positions;
2. enregistrement vidéo du mesurage pour utilisation ultérieure et conservation en archives;
3. soin apporté à l'orientation et à l'étalonnage du ShapeGrabber pour éviter des erreurs d'alignement dans les données.

Pour les rappels ultérieurs de la modélisation, voici ce qui est recommandé :

1. liaison additionnelle avec Polyworks pour résoudre la difficulté que représente le remplissage automatisé;
2. maintien de l'utilisation et utilisation accrue des outils d'édition évolués de Polyworks et plus de formation sur ceux-ci;
3. maintien de la révision et des mises à jour des ensembles de Polyworks et de Rhino;
4. plus d'examen ou d'utilisation de texturation des photos, ou les deux, pour les consoles et les tableaux de commande;
5. accès Internet sur place au soutien technique et accès aux bases de connaissances.

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1 INTRODUCTION AND BACKGROUND

[1] In previous call-ups of Array's standing offer for three-dimensional (3D) graphics modelling, detailed graphic models of three Canadian Forces (CF) helicopters were created or modified for Defense Research & Development Canada-Toronto (DRDC-Toronto) – the Griffon helicopter, the Sea King helicopter, and the Cormorant Helicopter. These models were produced from DRDC supplied laser scanner data, previously collected using Cyrax and ShapeGrabber laser scanners. These 3D graphics models are used for simulation, rehearsal and training including conducting interior reach studies of pilot and seat positions for aircraft.

[2] In the previous call-up, detailed interior and exterior modelling of the cormorant helicopter was completed.

[3] In this call-up, 3D graphics models of the CF Hercules CC130 aircraft (similar to that shown in Figure 1) were produced and verified.

Figure 1. Exterior Image of a Canadian Forces Hercules CC130 Aircraft

[4] The graphic models produced include polygon representations of both the aircraft exterior, and cockpit interior. The actual cockpit interior is fairly complex, as shown in Figure 2.

Figure 2. Interior Cockpit (With Pilot) of Hercules CC130 Aircraft

[5] In addition to polygon models, conventional surfacing was used to create objects with NURBS surfaces to represent the pedals and seats. Also, key control panels and consoles were similarly modelled.

2 DETAILS AND RESULTS OF INDIVIDUAL TASKS

2.1 Interior Graphics Modelling of Hercules aircraft

[1] The interior model of the Hercules cockpit was produced in two forms: a detailed polygon based representation from the laser scan data supplied by DRDC-Toronto, and a NURBS surface model for key objects derived from the polygon model.

[2] The NURBS surface model is space efficient, scalable, and convenient to work with. It is mainly used for representing critical control objects (sticks, pedals), seat positions and range of motions.

2.1.1 Alignment and Polygonization of Data

[1] DRDC-Toronto's contractor Innovision Inc. scanned the interior of the Hercules cockpit in February 2002 using a ShapeGrabber Laser Scanner. The cockpit data consisted of 95 images, with standard deviations of 350-1300 microns, and mean errors of +/-240 microns. These raw scans were aligned and processed using Innovemetric's Polyworks/Modeler software. The best achieved alignment results, as listed above indicate significant alignment error resulted from calibration related errors during the scanning, as discussed below. The standard errors are approximately twice as much as would be expected in these conditions and location, compared to similar Cormorant and Griffon data taken with the same sensor.

[2] Polywork's IMAlign was used to align scans with respect to each other. The standard error for the scan alignments was 350 - 1300 microns, with a point scan density interpolated to a 1 mm grid. Figure 3 shows the aligned point clouds in IMAlign.

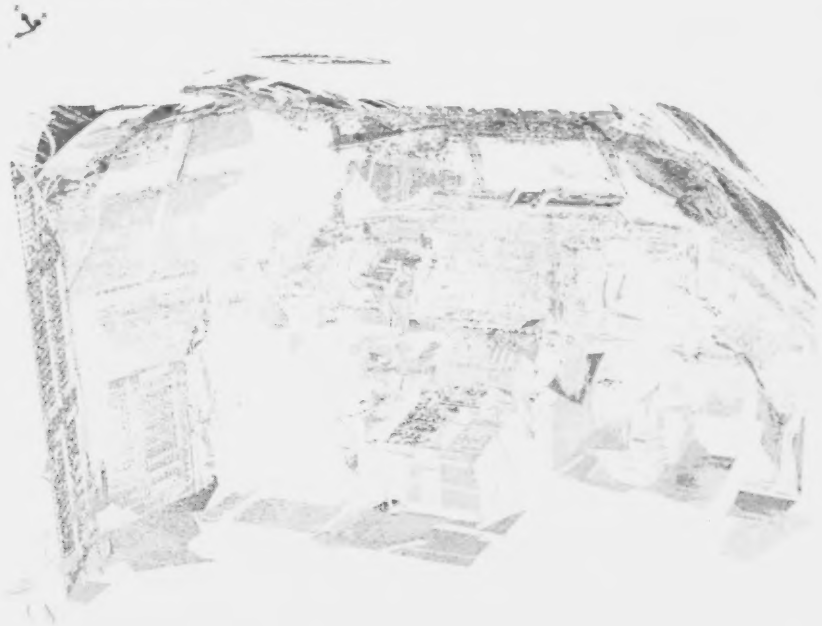

Figure 3. Point Cloud Scans of Aircraft Cockpit Interior

[3] Following notice from DRDC-Toronto, it was confirmed that the raw data from the ShapeGrabber scanner was subject to larger than expected alignment variation due to insufficient ShapeGrabber calibration. The ShapeGrabber scanner allows only certain head movements (such as pan or tilt) without requiring recalibration. Some movements were made that would require recalibration, but recalibration was not performed. The effect resulted in larger than expected alignment errors in IMAlign. The overall effect of the error appears to have increased the alignment errors by a factor of 2x, from the expected 200-600 microns standard error to approximately 400-1200 microns. It does appear however, that the error causes distortions that are partly compensated by the IMAlign best-fit least-squares alignment process.

[4] This alignment error effect was reported to the Scientific Authority. It was decided that given the 3-6 mm accuracy of the other laser scanner used for this aircraft, the Cyrax, as well as the normally expected 1-2 mm error in the 3D graphics modelling process, the alignment accuracy of the processed ShapeGrabber scans was sufficient to enable modelling of the cockpit to the required level of accuracy.

[5] There is also some evidence of movement of certain objects during the ShapeGrabber scans. This is most noticeable with the repeater flight command indicator panel on top of the glareshield and the throttle levers. Both are shown in Figure 4.

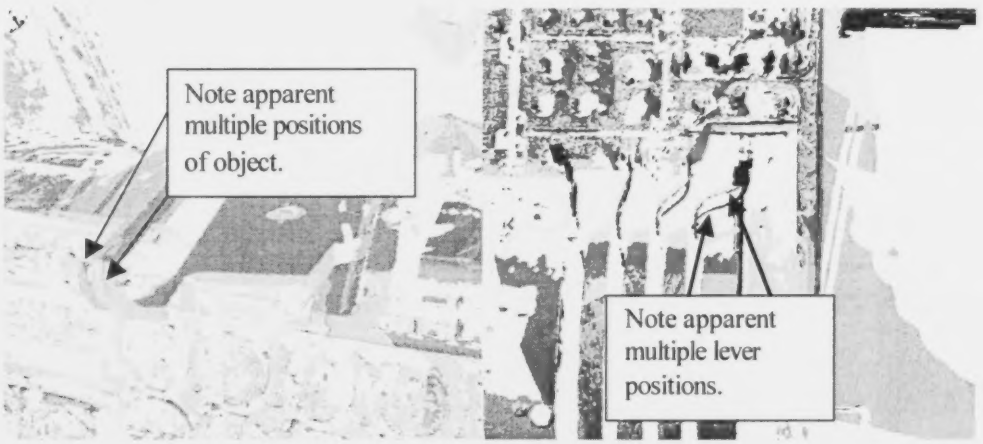

Figure 4. Images Showing Possible Movement of Objects During Interior Laser Scanning

[6] After the alignment was completed and verified, scan overlap was reduced using IMAlign. Next, the scanner point clouds were merged and polygonized using IMMerge. The following parameters were used for the merging, based on the standard deviation of the point cloud alignment averaging 0.75 mm:

a. Maximum Distance: 8mm
b. Sample Grid 1: mm
c. Smoothing Radius: 3 mm
d. Smoothing Tolerance: 2.25 mm
e. Overall tolerance reduction: 0.080 mm

[7] This merging resulted in an initial polygon model of 4.3 million Polygons. To work with this data efficiently, it was further reduced to 0.3 mm tolerance using IMCompress. The reduced interior polygon model contains approximately 1.9 million Polygons.

[8] Next, the interior polygon model was edited using IMEdit, removing all unconnected triangles (noise), and the polygon model was organized in the following logical object-based groups: sticks, seats, main consoles, upper console, back panel, floor, frame, and pedals. Each of these groups was colour coded and separated into separate polygon files to use in deriving the Rhino NURBS models. This base interior polygon model, shown in Figure 5, is used as the source data for both modelling Rhino NURBS objects, and also for verifying them and their positions. Range of motion scans for the pedals and seats were collected separately using the Cyrax laser scanner.

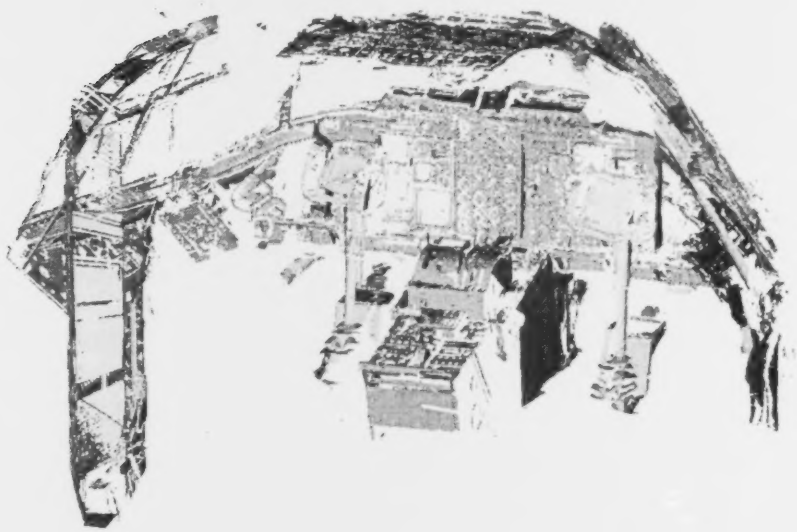

Figure 5. Polygon Representation and Functional Groups for Aircraft Cockpit Interior

2.1.2 Transformation of Data to Global Model Coordinate System

[1] The initial scan alignment and polygonization took place in an arbitrary 3D coordinate system, related to the scanner positions and orientations at the time of the measurement. For convenience in modelling and viewing results, the data was transformed into a global model space coordinate system, related to the logical construction of the aircraft. This datum definition and transformation was defined using IMInspect, part of the Polyworks\Inspector software.

[2] The datum was defined as follows. Planes were fit to both the floor of the cockpit, and the back wall of the center console. These planes were intersected to a line that lies approximately perpendicular to the longitudinal (symmetry) axis of the aircraft, on the floor surface. Another plane is then constructed by rotating the floor plane 90 degrees around this intersection line. This creates a plane perpendicular to the floor across the cockpit, also approximately perpendicular to the aircraft longitudinal axis. The origin is chosen on the line of rotation outside the cockpit area. The origin

point, intersection line, and rotated plane enable a point, line, plane (123) transform to this new datum. This relates all primary coordinate planes to the aircraft cockpit floor (the zero Z datum), the longitudinal axis (Y axis), and a mutually perpendicular X axis, transverse across the back of the cockpit. Figure 6 shows this datum definition and construction.

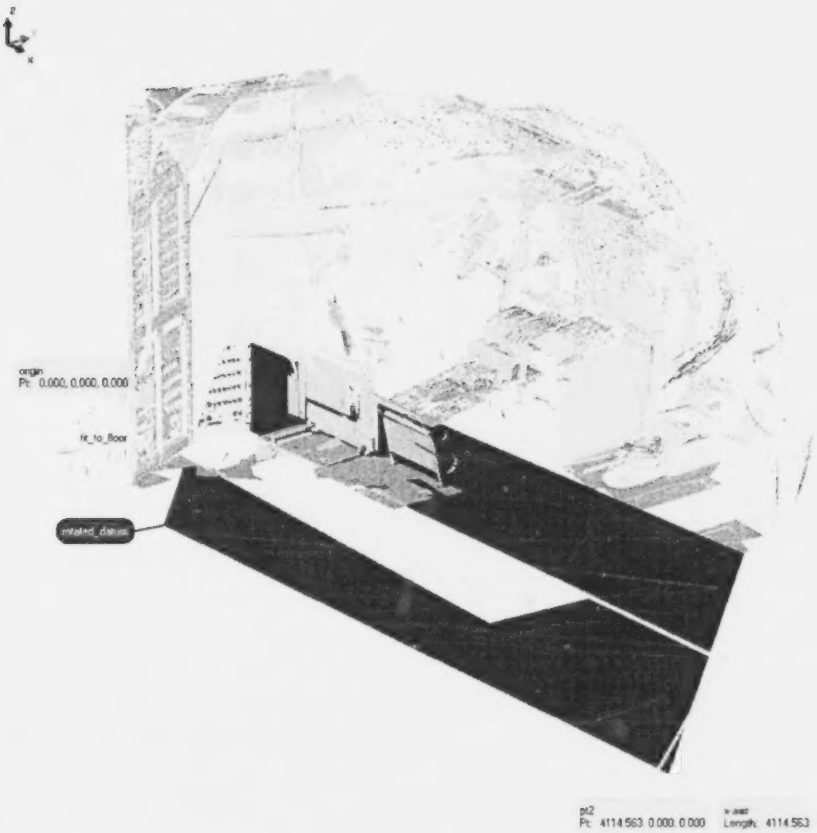

Figure 6. Definition of Global Model Coordinate System

[3] This global model coordinate system, or datum, is used for the rest of the project, including aligning the exterior shell to this system, described later in this report.

2.1.3 Alignment and Processing of Cyrax Data for Seats and Pedal Motion Limits

[1] In addition to the ShapeGrabber scan data of the cockpit interior, Cyrax data of the same area was also supplied. This data contained both the interior consoles, and the seats and pedals in both front and back positions (forward and aft positions).

[2] Also, separate scan data of the pilot and co-pilot seats was supplied, apparently scanned after being removed from the aircraft. These scans also contain height information, as scans appear to have been made in both minimum and maximum height positions of the seats.

[3] As the seats were scanned both inside and outside of the aircraft (inside forward and aft), accurate repositioning of the seats, as well as range of motion representation was much simpler than with the Cormorant and Sea King helicopters. In both of those models, seats were ONLY scanned outside of the cockpit, and sparse rail data was used to reposition them.

[4] The alignment of the Cyrax Interior data, shown in Figure 7, consisted of 24 scans, with standard deviations of 2.3-4.2 mm, and mean errors of +/-0.1 mm. Polywork's IMAlign was used to align scans with respect to each other. The data was interpolated with a grid density of 5 mm.

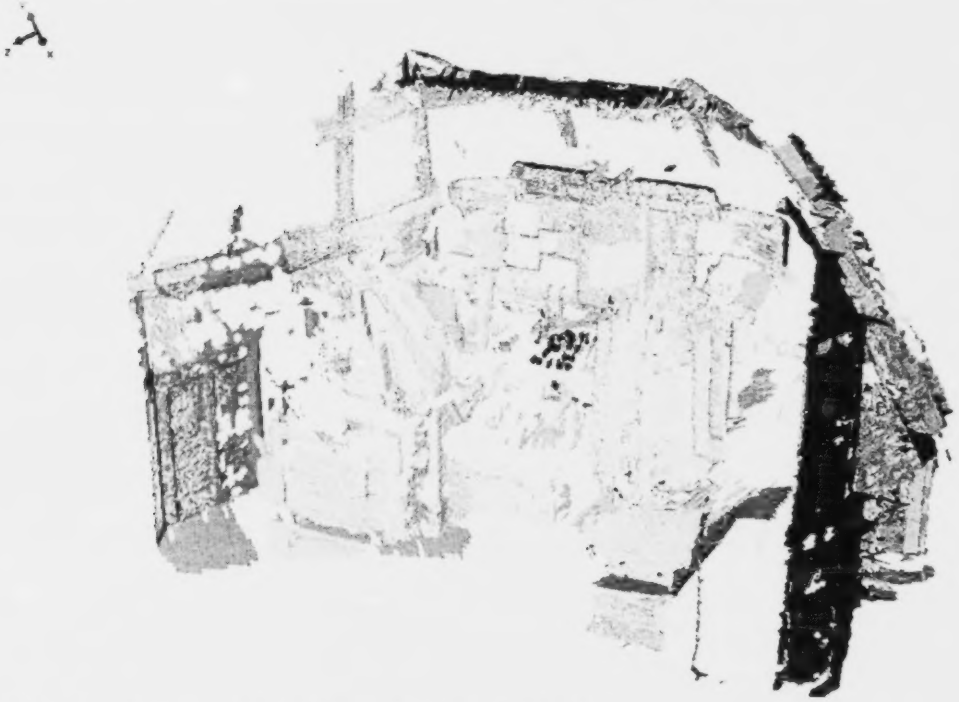

Figure 7. Alignment of Cyrax Laser Scan Data of Cockpit

[5] After the alignment was completed and verified, scan overlap was reduced using IMAlign. Next, the scanner point clouds were merged and polygonized using IMMerge. The following parameters were used for the merging, based on the standard deviation of the point cloud alignment averaging 3 mm:

a. Maximum Distance: 30 mm
b. Sample Grid: 5 mm
c. Smoothing Radius: 15 mm
d. Smoothing Tolerance: 9 mm
e. Overall tolerance reduction: 0.060 mm

[6] This resulted in an interior Cyrax polygon model containing 288 000 polygons, after being tolerance reduced to 0.6 mm. This polygon model was also divided into functional groups such as panels, pedals, seats, etc.

[7] In addition, the scans of seats taken outside the cockpit were similarly processed and Polygonized. Figure 8 shows the polygon models of the pilot and co-pilot seats. The seats consist of approximately 100 000 polygons each, after tolerance reduction to 0.5 mm.

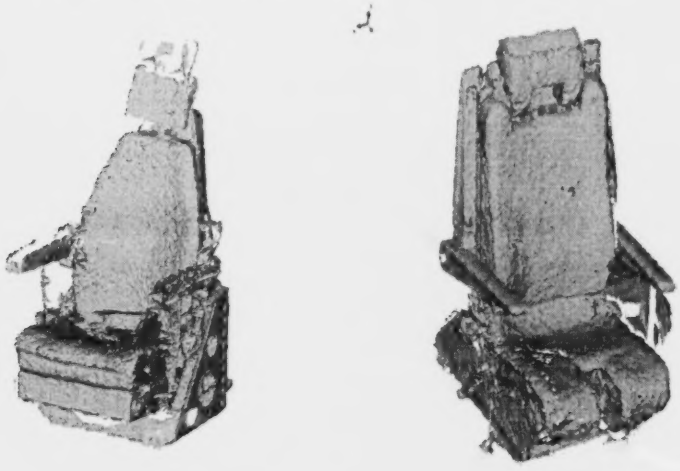

Figure 8. Polygon Models of Pilot and Co-Pilot Seats From Cyrax Scan Data

2.1.4 Interior Surfacing and Range of Motion of Key Objects Using Rhino

[1] Key objects and control surfaces inside the cockpit were modelled using conventional NURBS surfaces with the Rhino software package. These objects were modelled from the interior polygon data, and the main movable control objects were also modelled in extra positions at their extreme limits of range of motion.

[2] These Rhino NURBS objects may be conveniently used in reach and accommodation studies. Rhino can export these objects to a variety of NURBS or polygon formats to use with other software packages like Safework.

2.1.4.1 Consoles and Control Panels

[1] The main surfaces of the following control panels were surfaced in Rhino: the front control panel, glare shield, center consoles, upper consoles, side consoles and circuit panels, and back panels. With the exception of critical controls identified by the Scientific Authority, the individual controls on these panels were not modelled conventionally, as they may be better depicted through photo texturing. The panel objects can be used to evaluate reach limits, as they are the farthest points from the pilot/co-pilot positions. In addition, the front panel glare shield was also accurately modelled using Rhino objects. Figure 9 shows the resulting objects.

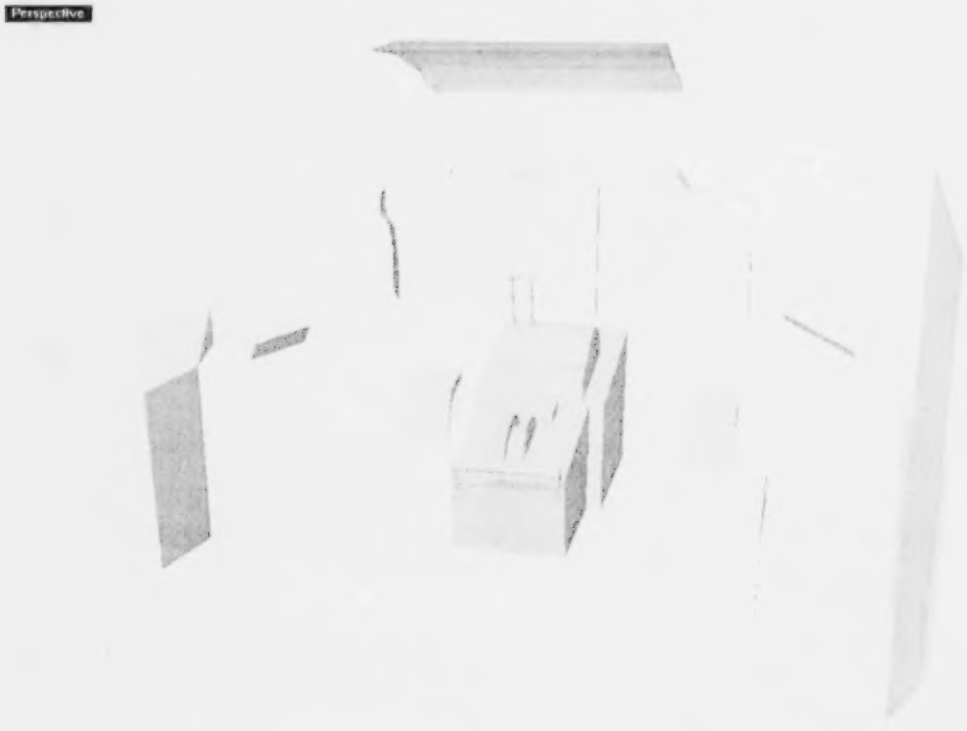

Figure 9. Console and Control Panel Objects

2.1.4.2 Pedals

[1] A pedal object was surfaced based on the interior polygon model. Range of motion for the pedals was determined primarily from the ShapeGrabber interior polygon model. Note that the pedal range of motions appears to have been scanned by setting the pilot's pedals at one extreme position, and the co-pilot's at the other. As it is assumed that both sets of pedals are mechanically linked, the range of motion from front to back is assumed to be identical for both sets of pedals. Cyrax scan data of the range of motions also supports this assumption.

[2] Based on the scans and consultation with DRDC authorities, the pedal assemblies were translated into forward and aft positions only. The Rhino objects were modelled and grouped according to this information, consistent with the individual scan locations. They are located to best fit the polygon model.

[3] Figure 10 shows the pedal objects and range of motions.

Figure 10. Control Pedal Objects

2.1.4.3 Yokes

[1] Yoke objects were surfaced using the interior polygon model. Range of motion for the sticks was not located in any of the scan data. The Scientific Authority confirmed that it was possible that they were not movable during the scanning.

[2] The center of the yoke contains map clips and holders. During the scanning and digital imaging, the map holders contained paper maps that obscured the actual holder, and also the center of the yoke. Thus, it is noted that the graphical models, dimensions, and position of the map holders and yoke center may not correctly represent the actual objects.

[3] There are numerous controls located on the yoke, including switches, buttons, and dials. Scan data taken on the yokes was not sufficient to accurately model these controls or their locations. Some controls were added to the model based on the limited scan and digital image information available. It is noted that these controls may not be accurately represented in the models.

[4] Figure 11 shows the Yoke objects, controls, and map clips/holders.

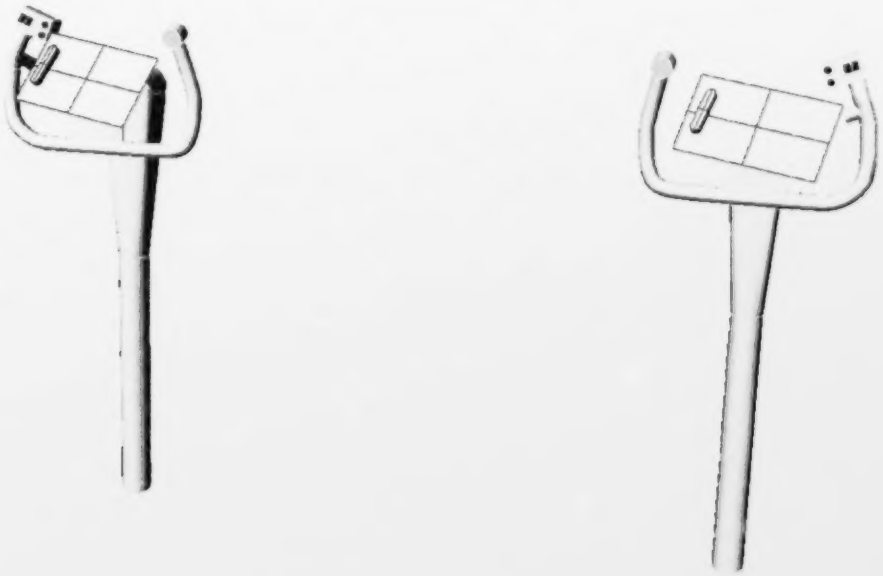

Figure 11. Yoke and Map Holder Objects

2.1.4.4 Seats and Seat Cushions

[1] The pilot positions and seat range of motions are represented graphically by modelling the seat cushions in Rhino. Figure 12 shows the Rhino seat cushion representation.

[2] Note that the pilot and co-pilot seats are considerably different in this aircraft. Each seat contains models of the front cushion surface, the top of the armrests, and the front of the head supports. To reduce polygon counts, the frames and housings were not modelled. It is noted that the backs of the seats aren't modelled due to limited time and scan data available.

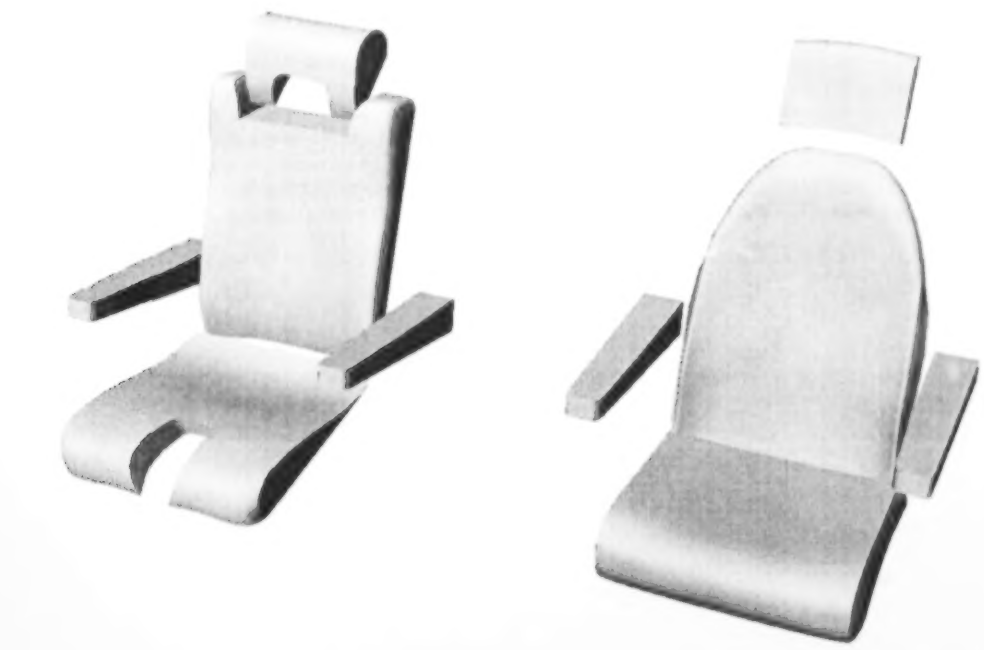

Figure 12. Seat and Seat Cushion Objects

[3] The scanned seat range of motions consists of forward and backward translations, up and down translations. These forward, back, up and down positions are represented as new layer objects in Rhino, grouped by position and rotation. The forward back limits were derived from the Interior Cyrax models, while the up and down limits were derived from Cyrax scans taken of the seats that were removed from the aircraft.

2.1.4.5 Critical Control Modelling

[1] At the request of the Scientific Authority, graphical representations (using NURBS in Rhino) were made for certain identified "critical controls".

[2] A complete list of critical controls was supplied by Robert Mertens of DRDC-Toronto. The list consists of the following:

a. Rudders (pedals)
b. Throttles (levers)
c. Yoke
d. Flap lever
e. Fire T-Handles
f. Condition levers air start
g. Dual nose wheel and throttle
h. Engine starter switches
i. Repeater flight command indicator panel
j. Enunciator Panel
k. Jump light
l. Prop. Governing control switches
m. Brake select switch
n. Engine hydraulic pump switches
o. Landing gear handle
p. Air drop chute release switch (ADS)

[3] Figure 13 identifies the locations of the critical controls using the letters in the above list as a legend.

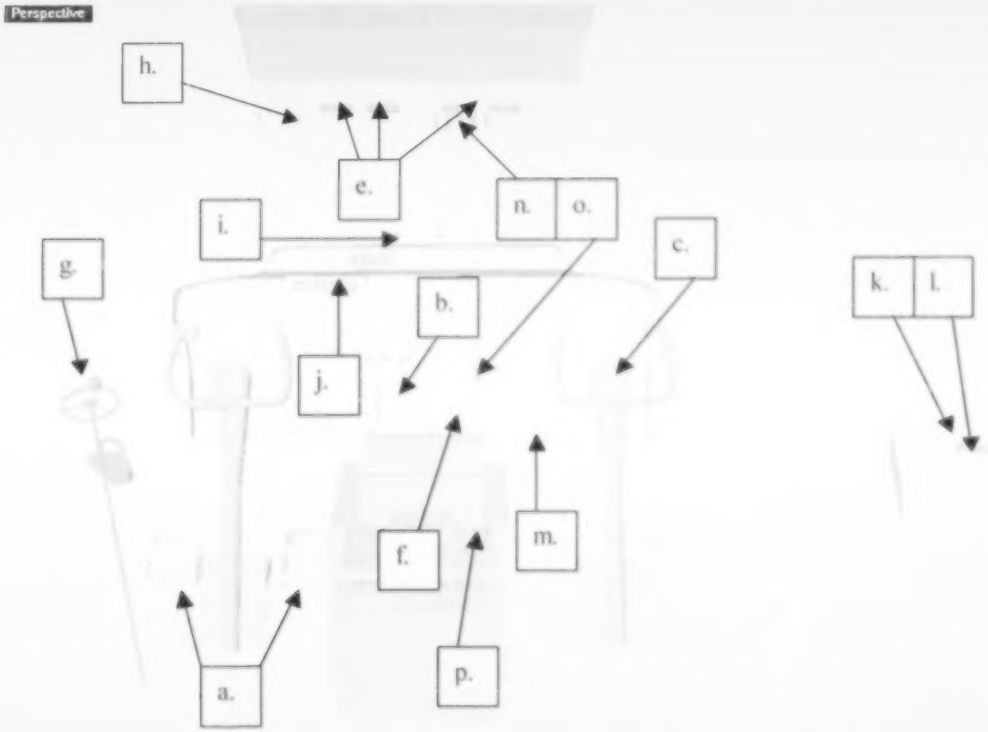

Figure 13. Critical Control Object Locations and Models

[4] All of the above critical controls were added to the model, with the exception of the Flap lever. As there were no scan data or digital images provided to indicate the shape of this lever, it was necessary to omit it.

[5] It is noted that some of the critical switches were difficult to model given the limited resolution and coverage of interior scan data. As a result, the precise locations and shape of the switches listed above (engine starter, hydraulic pump, ADS) may differ slightly from the actual objects. This difference is mainly due to incomplete ShapeGrabber scan data, and is also the result of having insufficient digital images available. The switches listed above could not be conclusively identified, and thus for modelling purposes are represented by either cylinders and/or rectangular solids.

[6] Also, to reduce modelling time and limit polygon counts, the above objects are generally represented by simplified geometrical primitives such as points, planes, cylinders, extruded solids and/or spheres.

2.1.5 Verification of Interior Objects

[1] For this project, all modelled surfaces were verified using IMInspect in comparison with the initial raw interior polygon model.

2.1.5.1 Consoles and Control Panels

[1] Figure 14 shows the error map for the modelled center panel and front consoles and control panels. The mean error of the 7559 points was found to be –0.4 mm, with the standard error being 2.1 mm.

[2] Note that the modelled surfaces are fit to the base planes of the panels and consoles, ignoring control switches, knobs, dials, etc, which were not modelled in this call-up. These controls are mounted on the surface, and affect the IMInspect colour error map. Some deviations represent the thickness of these controls, as opposed to surface errors of the modelled surface. Also note there are significant void areas in the error map below. These are areas without scan data, and appear to correspond to cathode-ray-tube screen displays (which may be too reflective for laser scanning).

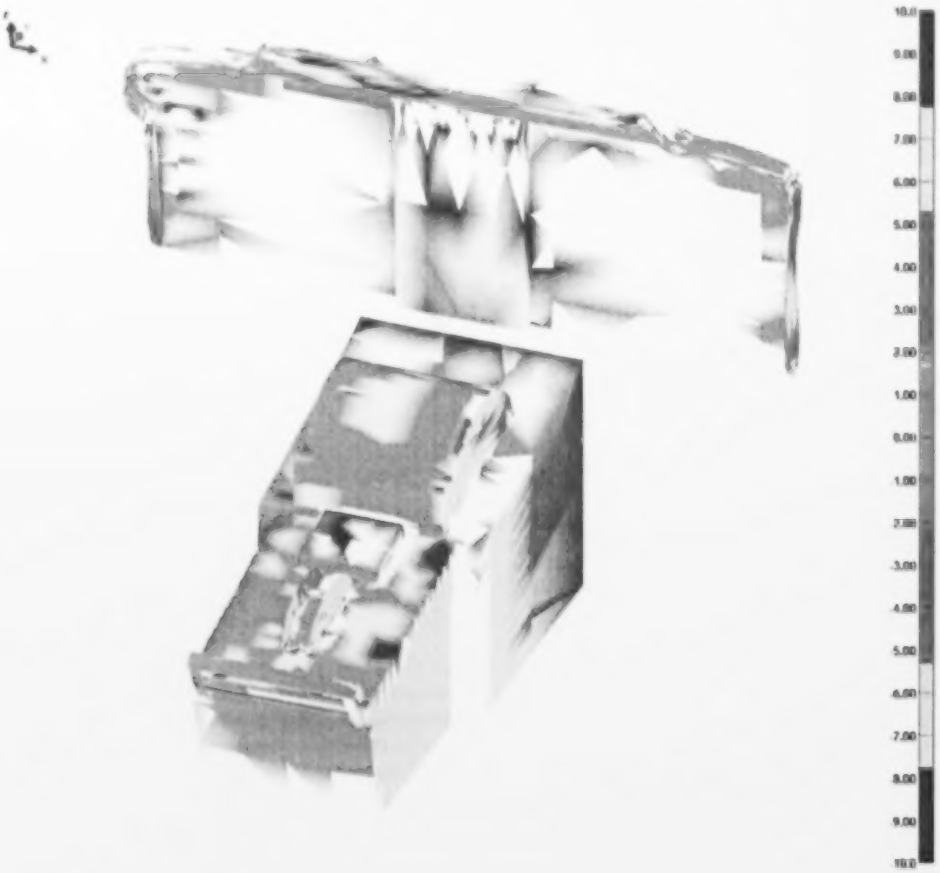

Figure 14. Error Map of Console and Control Panels (mm)

2.1.5.2 Pedals

[1] Figure 15 shows the error maps for the modelled pedals with respect to the raw interior polygon model. The mean error of the 3162 points was found to be –0.7 mm, with the standard error being 2.5 mm. Some of this error is due to scan noise surrounding the unmodelled pedal support rails and fixtures, and also unmodelled company textured logos embedded in the pedal surface.

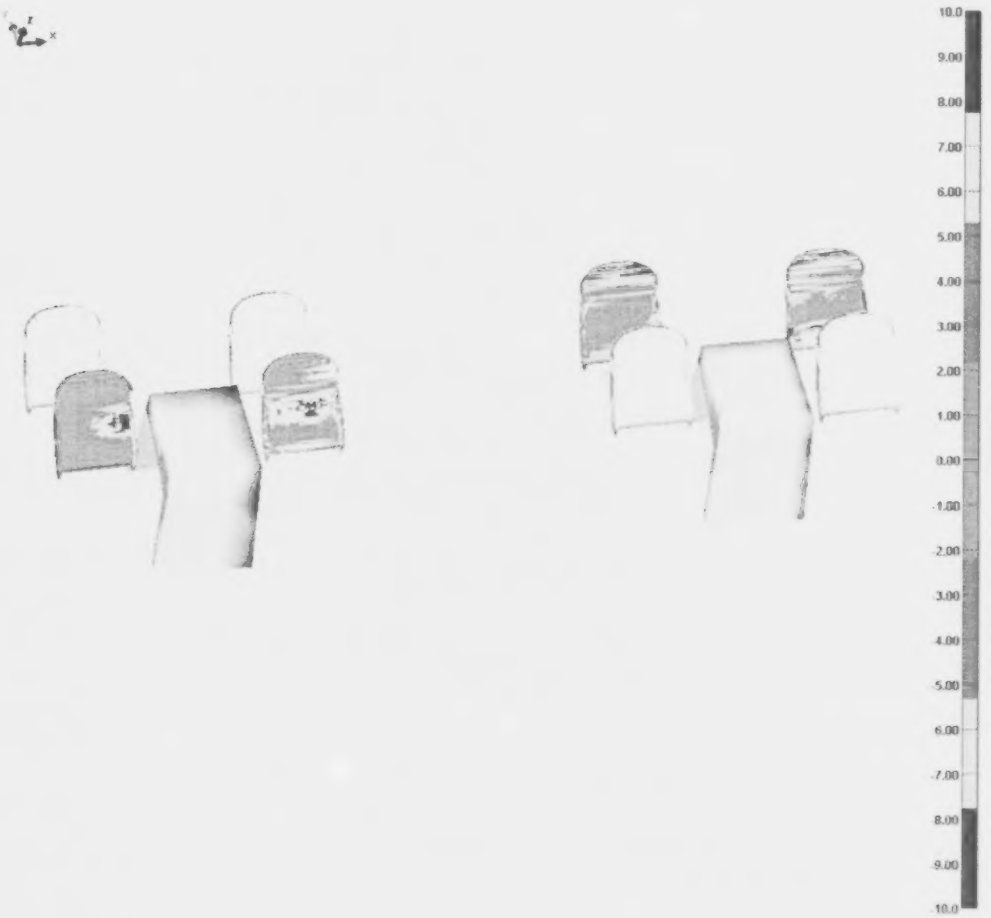

Figure 15. Error Maps of Control Pedals (mm)

2.1.5.3 Yokes and Other Critical Controls

[1] Figure 16 shows the error maps for the modelled yokes and other critical controls, with respect to the raw interior polygon model. The mean error of the 29804 points was found to be -0.2 mm, with the standard error being 2.6 mm.

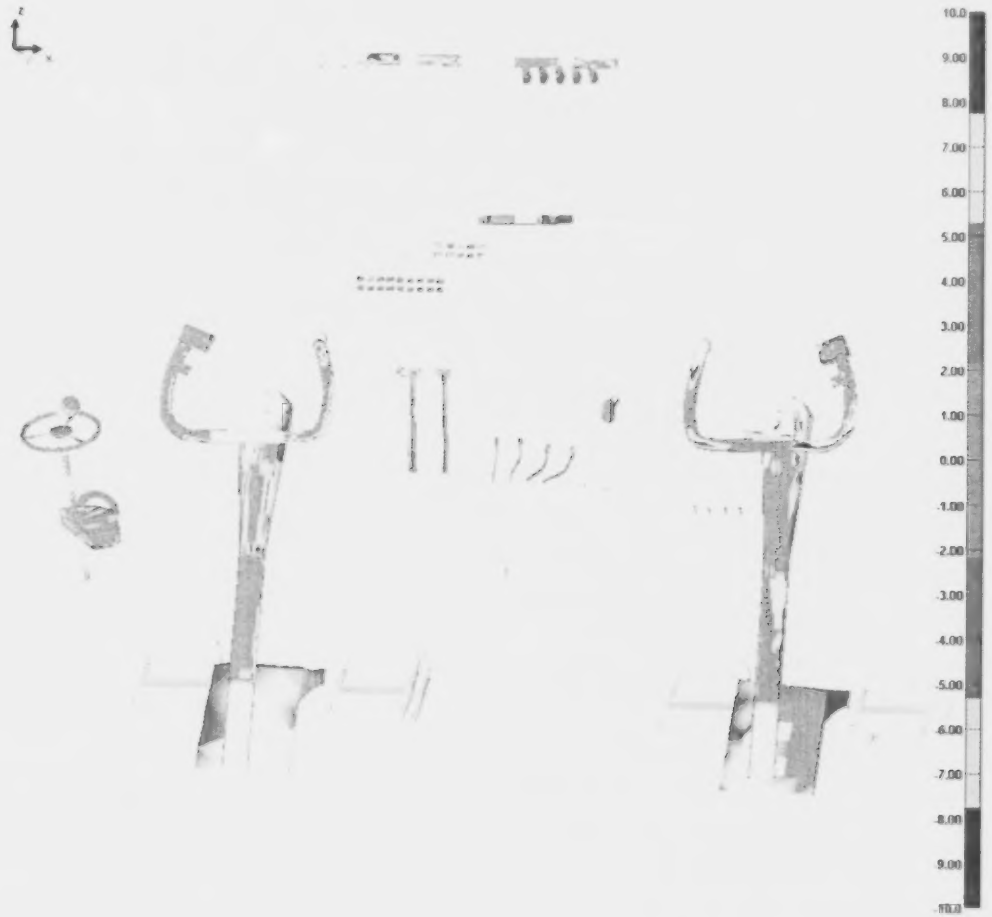

Figure 16. Error Maps of Collectives (Point Clouds) (mm)

2.1.5.4 Seats and Seat Cushions

[1] Figure 17 shows the error maps for the seat cushions, with respect to the raw polygon model. The mean error of the 37653 points was found to be -0.1 mm, with the standard error being 2.6 mm. Figure 17 illustrates the error for the seats in the down and back extreme position. The other positions were also verified, and similar results were obtained.

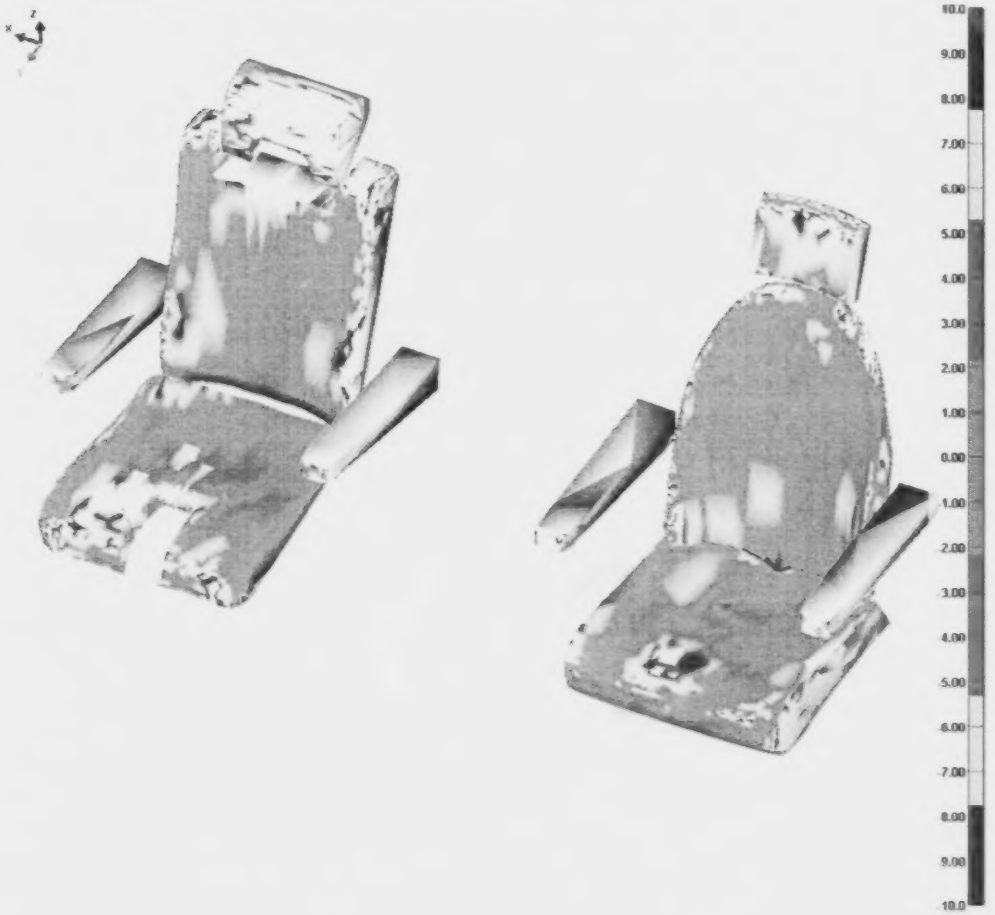

Figure 17. Error Maps of Seats and Seat Cushions (mm)

2.1.5.5 Overhead Console and Side Control/Circuit Breaker Panels

[1] Figure 18 shows the error maps for the overhead console, with respect to the raw interior polygon model. The mean error of the 401 points was found to be –0.3 mm, with the standard error being 2.5 mm. Note the voids in the error map represent areas without scan data.

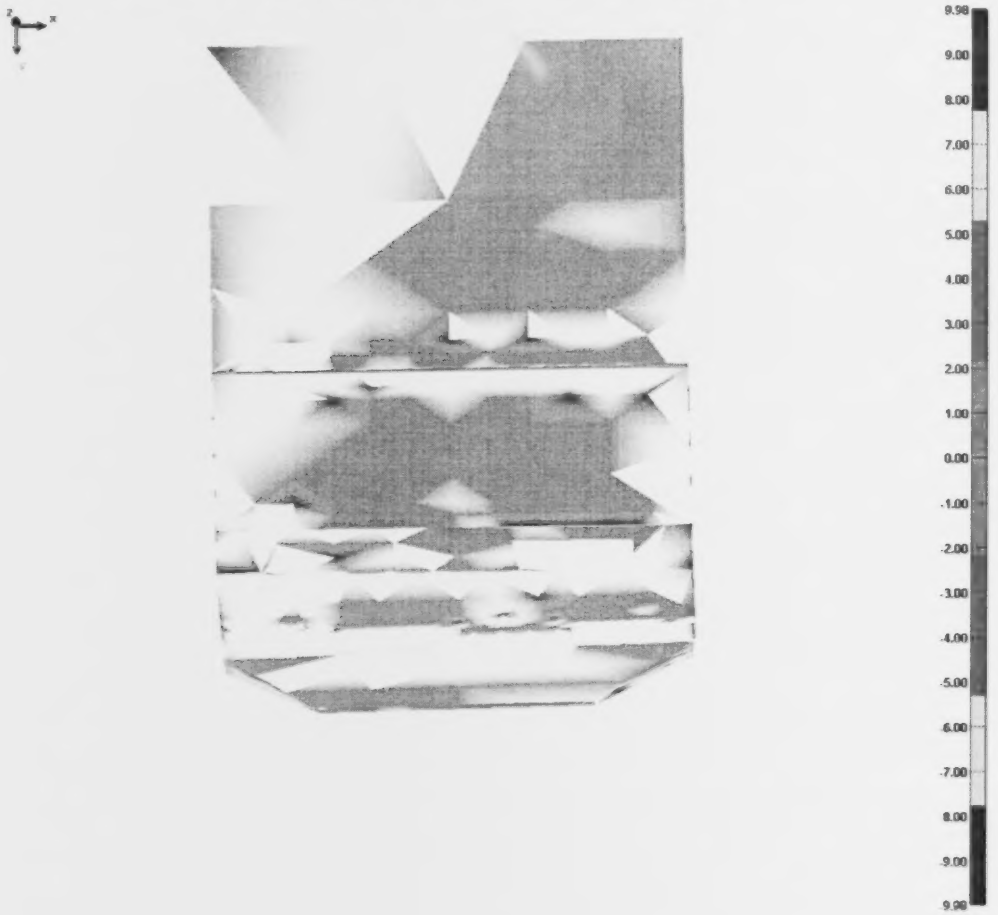

Figure 18. Error Map for Overhead Control Consoles (mm)

[2] Figure 19 shows the error maps for the side panels, with respect to the raw interior polygon models. The mean error of the 1359 points was found to be –0.1 mm, with the standard error being 2.7 mm.

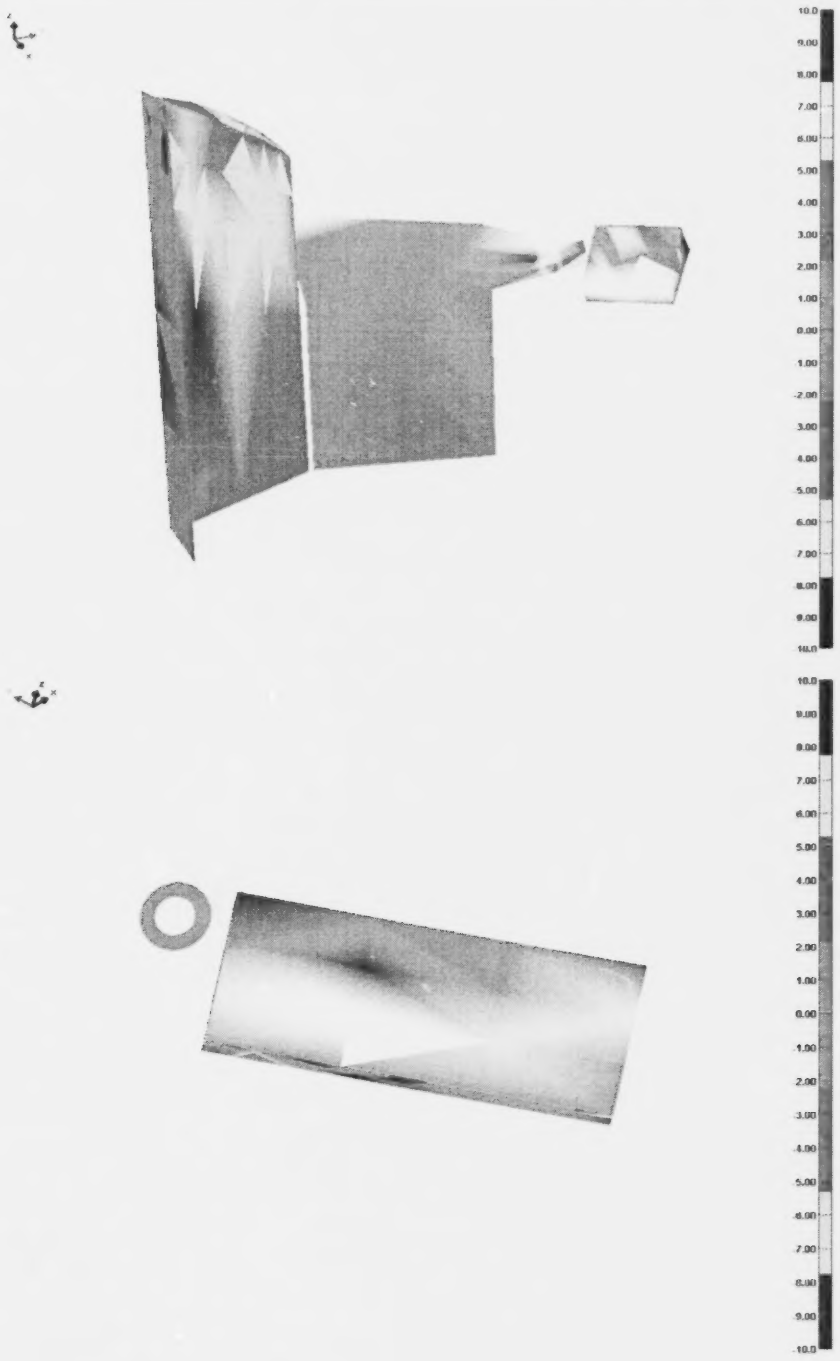

Figure 19. Error Map for Side Control Panels (mm)

2.2 Exterior Graphics Modelling of Hercules CC130 Aircraft

2.2.1 Alignment and Polygonization of Data

[1] The exterior of the Hercules was previously scanned using DRDC-Toronto's Cyrax laser scanner, with measurement accuracy of 3-6 mm. DRDC-Toronto provided this data for the callup.

[2] The 68 scanner point clouds were aligned using IMAlign. Figure 20 shows the point clouds after alignment and before overlap reduction. The point grid density is 10 mm, and the standard error for the alignment varies from 1 to 4 mm, averaging 2.5 mm.

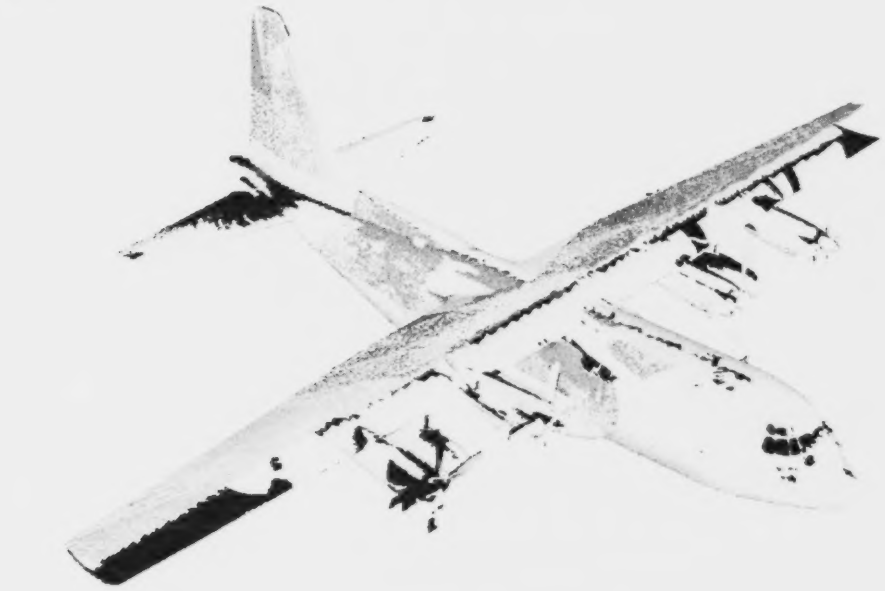

Figure 20. Point Cloud Scan Model of Shell

[3] Once alignment convergence was obtained, the model was polygonized using IMMerge with the following parameters:

a. Maximum Distance: 20 mm
b. Sample Grid: 10 mm
c. Smoothing Radius: 30 mm
d. Smoothing Tolerance: 5 mm
e. Overall Tolerance Reduction: 0.5 mm

[4] Figure 21 shows the initial unedited Polygon model. This unedited model consisted of approximately 1.6 million polygons.

[5] The original scans were taken using metres as the measurement unit. For compatibility with ShapeGrabber data, the model was scaled to convert the units to millimetres. Also, polygons were logically divided into appropriate groups such as hull, engines, landing gear, tail, etc.

Figure 21. Unedited Polygon Model of Exterior Shell

2.2.2 Advanced Polygon Editing and Reconstruction

[1] The raw polygon model of the Hercules Exterior required challenging polygon editing and reconstruction for the following reasons:

- ?? Some scanned areas were obscured by features on the exterior, causing shadows. These are areas with no scan data, or partial data. This is an unavoidable consequence of scanning the upper areas of the aircraft from an elevated lift.
- ?? Areas such as windows did not reflect the Cyrax laser; instead, it penetrated into the interior. This has two effects: no surface data on the windows, and significant noise inside the model.
- ?? There are noticeable multipath errors and noise around the edges of features such as windows, intake openings, and other fixtures.
- ?? Due to access, line-of-sight, and minimum stand-off considerations, part of the bottom of the aircraft was not scanned.
- ?? The surface scan data itself is subject to measurement errors of 3-6 mm. This causes considerable noise and bumpiness that must be smoothed in the processing.
- ?? Aircraft surface colour variations, especially black areas like logos, flags, text, etc., cause poor laser return signals resulting in missing data and/or noisy data around these areas.

[2] Other, smaller sources of potential error are site-specific refraction, vibration of sensor and or object, dust, lighting effects, temperature variations, etc.

[3] Polyworks's IMEdit program provides extensive tools for surface editing, reconstruction, smoothing and filtering. However, to achieve effective results, an average amount of time was required, approximately 1/4 of the total time budget for this project. Some of the advanced techniques used are briefly described below.

2.2.2.1 Edge Reconstruction

[1] Polyworks\Modeler V8 contains a number of existing and new tools for edge reconstruction. These tools enabled the typical edge effects and noise caused by effects such as multipath to be removed in a semi-automated process.

[2] Figure 22 shows a sample area before and after successful edge reconstruction. Approximately 50 edges were reconstructed using this technique.

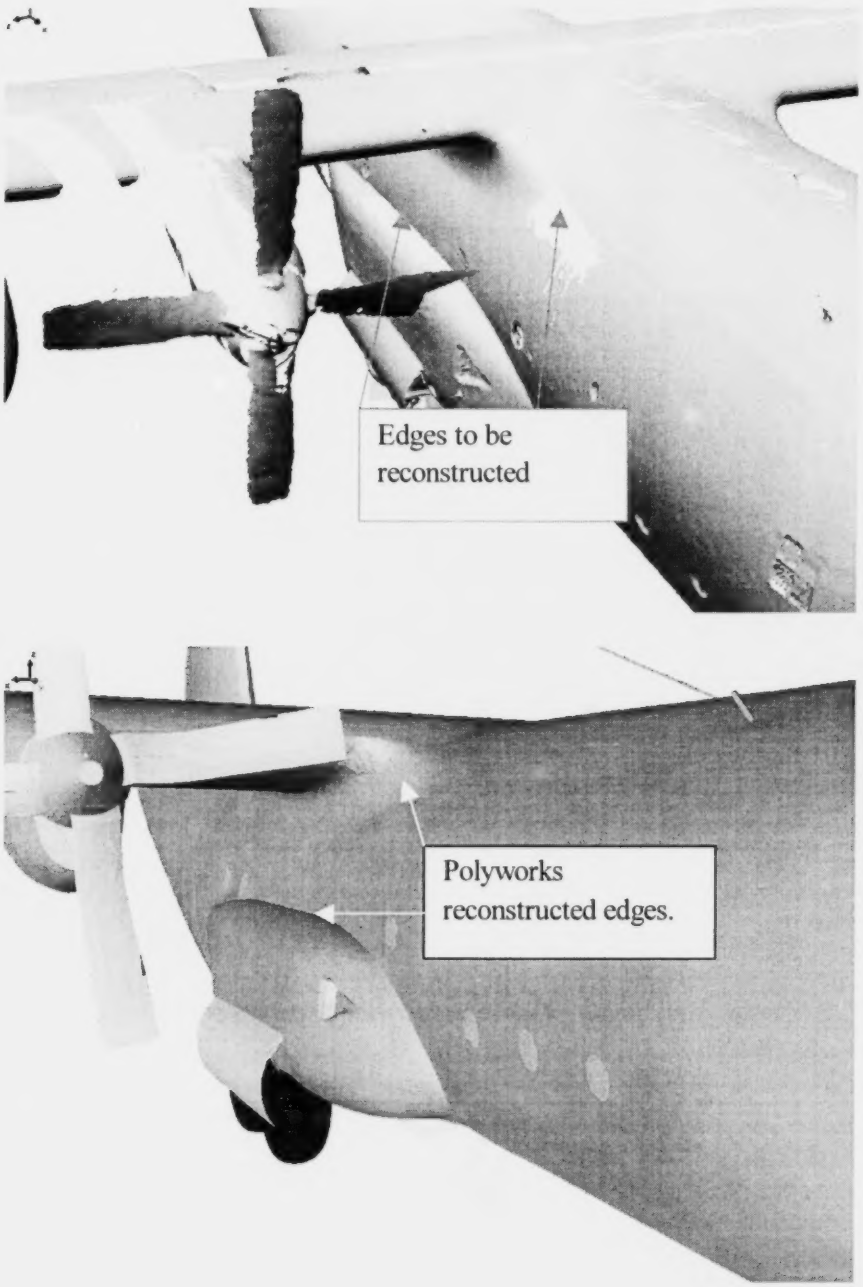

Figure 22. Example of Polyworks Edge Reconstruction Using IMEdit's Tools

2.2.2.2 Filtering and Smoothing of Data, Hole Filling

[1] The majority of time spent in the exterior polygon editing was spent smoothing, filtering surfaces, and filling holes. Although IMEdit's V8 has an improved hole-filling routine, it was found to not provide the desired results, and had some unsatisfactory side-effects, namely creating new holes. This side effect has been reported to Innovemetric for future action. As a result, most holes were filled manually using triangulation and manual selection of polygons/vertexes.

[2] Over 200 Bezier surfaces were fit to the model for use in smoothing and reconstruction. Also, global filtering, smoothing, and mesh optimizing were used to improve the model. The most challenging areas to edit/reconstruct were located along sharp edges with high curvature. These areas contained considerable noise and/or degenerate triangles. Also, the edge areas were most subject to data voids from shadow effects.

2.2.2.3 Modelling of External Fixtures and Objects

[1] In addition to the hull and window editing and smoothing, there were a number of external fixtures on the aircraft surface including – engines, propellers, fuel tanks, landing gear, antenna, aircraft doors and windows, and landing gear doors. Each of these fixtures contained partial scan data, some of it fairly noisy. Rhino conventional NURBS surfacing was used to reconstruct these fixtures from the partial scan data. The Rhino surfaces were then polygonized and re-imported into the exterior polygon model. Figure 23 shows these fixtures in the final exterior model.

Figure 23. Models of External Fixtures of Aircraft

2.2.3 Transformation to Global Model Coordinate System

[1] After the exterior modelling and reconstruction was completed locally, the entire exterior shell and fixtures were aligned with respect to the previously edited interior model, into the Global Model coordinate system.

[2] The primary common features to enable this alignment are the edges of the cockpit windows. This frame was captured using ShapeGrabber from the inside, and could be fit to the reconstructed cockpit windows from the exterior Cyrax scan data. This enabled approximate alignment using Iminspect's multiple point alignment mode, and also its best-fit alignment mode. To improve the accuracy of the alignment, adjustments to six degrees of freedom (three translations and three rotations) were made using Iminspect's manual alignment controls. The displays were set to wireframe, and the interference colour pattern between the exterior and interior window frames was observed. Also, the compare data to reference inspection feature was used (with vector display) to help in tuning the alignment.

[3] The alignment of exterior shell to interior cockpit is verified by comparing the fitting errors of the transformed raw Cyrax point cloud scan of the exterior window frame with the Polygonized ShapeGrabber scanned model of the interior frame, with the resulting colour error map shown in Figure 24. The mean error of this fit is 0.5 mm, and standard error is 5.9 mm. The majority of this error is due to the significant scanner noise occurring around the window frame, and also is affected by minor surface variations that were not modelled in order to reduce the total polygon count.

Figure 24. Error Map of Exterior to Interior Alignment

2.2.4 Verification of External Model and Fixtures

[1] After editing and transformation of the shell were completed, the modelled surfaces and objects were compared to the original polygon model using IMInspect. Note that the final model is compared to the original data including its noise and edge effects. In the colour maps below, certain areas may appear to contain large variations from the modelled surface, these are also side-effects of extraneous noise, and do not represent model errors. Other areas that appear as grey are the result of comparison to areas that have no data, due to effects such as shadowing.

[2] Figure 25 shows the colour error map of the hull with respect to its original data. The mean error of this comparison is –2.5 mm and the standard error is 7.2 mm.

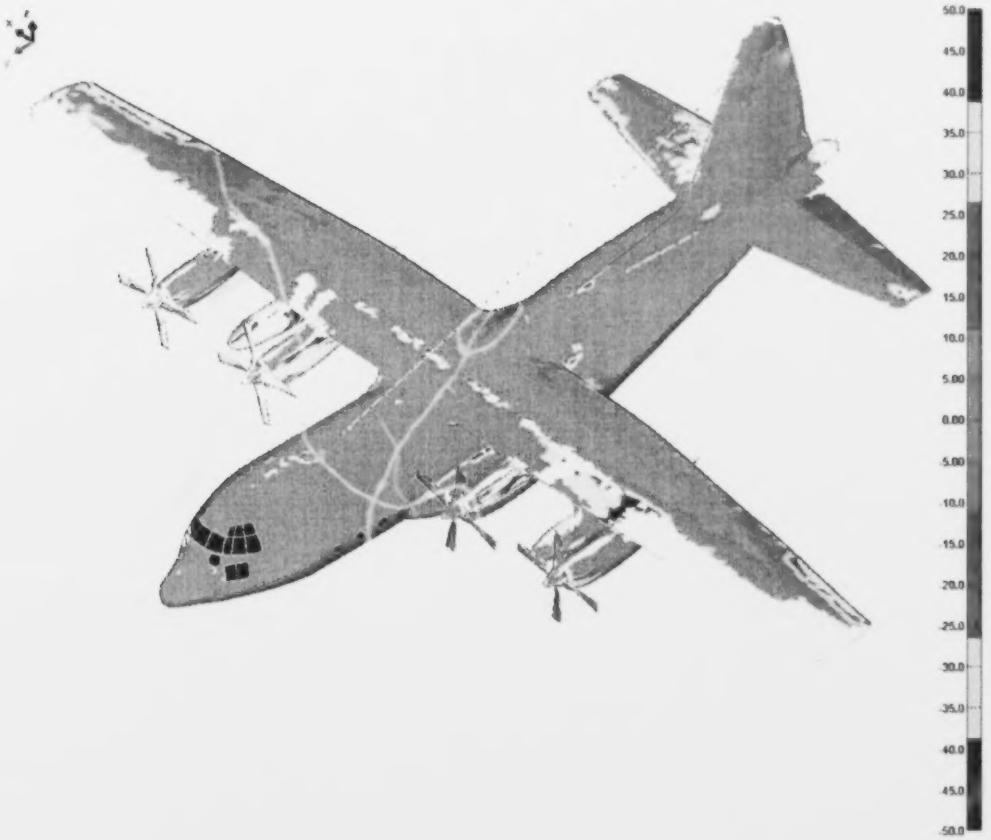

Figure 25. Error Maps of Hull (mm) (cont'd on next page)

Figure 25 Error Maps of Hull (mm)

[3] Figure 26 shows the colour error map of the wheels with respect to its original polygon model. The mean error of this comparison is –2.1 mm and the standard error is 5.3 mm.

Figure 26. Error Map of Wheels (mm)

[4] Figure 27 shows the colour error map of the remaining exterior fixtures with respect to their original data. Note that the windows generally do not have accurate reference scanner data for this comparison. The mean error of this comparison is -0.6 mm and the standard error is 5.7 mm.

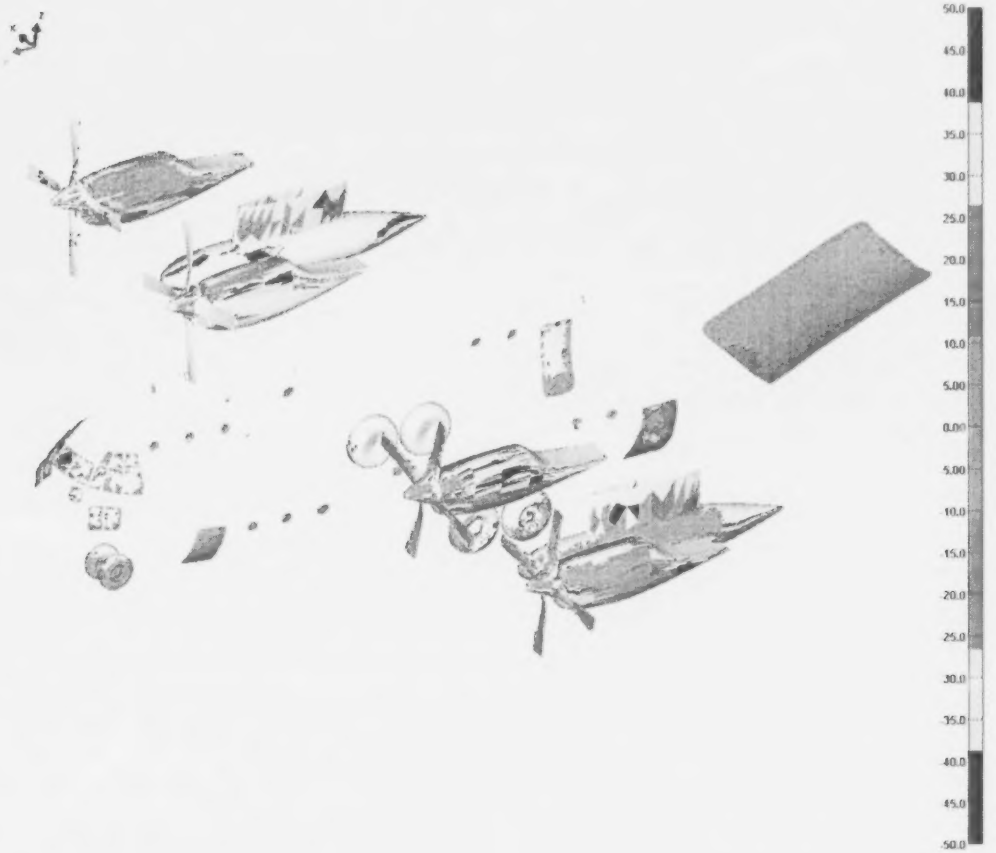

Figure 27. Error Map of Other External Fixtures (mm)

3 FINAL MODEL AND DELIVERABLES

[1] In addition to this report, there are three primary deliverables from this project.

3.1 Exterior Polygon Model

[1] This file, named Hercules_ext_final.pol contains approximately 330456 Polygons, the result of tolerance reduction to approximately 1 mm. It also contains 14 logical polygon groups for various objects and areas like hull, windows, wheels, etc. A typical view of this model is shown in Figure 28.

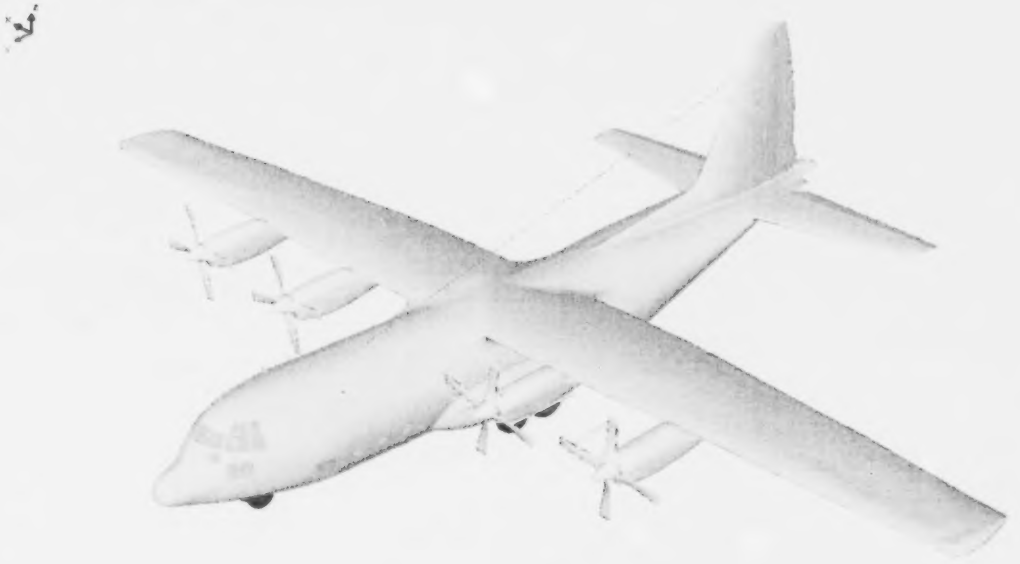

Figure 28. View of Final Edited Polygon Model of Aircraft Exterior

3.2 Interior Polygon Model

[1] This file, named Hercules_int_final.pol contains approximately 1805000 Polygons, the result of tolerance reduction to 0.3 mm. It also contains 12 logical polygon groups for various objects and areas like seats, panels, floor, frame, etc. One view of this model is presented in Figure 29.

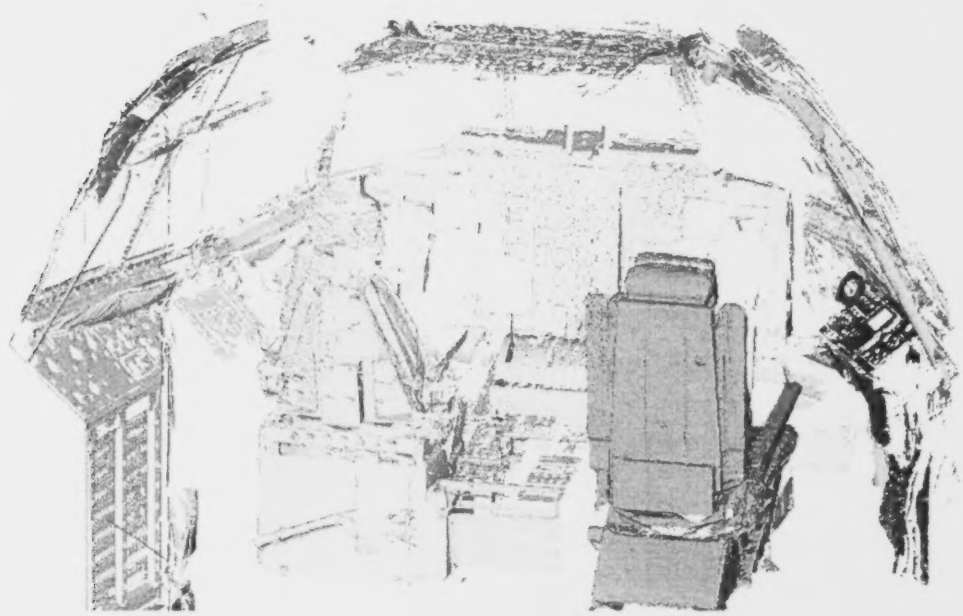

Figure 29. Final Edited Polygon Model of Cockpit Interior

3.3 Interior Rhino NURBS Model

[1] This file, named Hercules_int_final.3dm contains surface NURBS models of key controls and panels. The objects are stored in logical layers, and also represent range of motion for all controls and seats. Note that from Rhino, the entire model or parts of it (like individual components) can be exported into a variety of formats including IGES, STL, and OBJ. This enables polygonization with scalable resolution. One view of this model is presented in Figure 30.

Figure 30. Final Rhino NURBS Model of Key Interior Objects and Controls

4 SUMMARY OF FINDINGS AND RECOMMENDATIONS

[1] Three graphics models of the Hercules aircraft were delivered for this call-up – the exterior, interior, and key interior pilotage objects. These Polygon and NURBS surface models are scalable, and logically arranged in groups and/or layers. They also represent graphically the range of motions in the cockpit of the cyclics, collectives, pedals, and seats.

[2] An external mean accuracy of less than 3 mm, and standard error of 6-9 mm for modelled areas of interest were verified with respect to the original data. An interior mean accuracy of less than 1 mm and standard error of 2-3 mm for modelled areas of interest were similarly verified. This is consistent and compatible with the accuracy of the laser scanners and their data.

[3] The following advanced techniques were used in the Hercules modelling:

1. Polyworks rigorous alignment and best-fit least squares transformation operations.
2. Extensive IMEdit surface reconstruction using Bezier surfaces.
3. Extensive surface filtering and smoothing operations.
4. Rhino conventional NURBS surfacing.
5. IMInspect verification of modelled surfaces and objects.
6. Polyworks semi-automated edge reconstruction.
7. Logical grouping and layering of objects and models.
8. Definition of a suitable global model coordinate system.
9. Extensive manual polygon editing and hole-filling.
10. Polyworks IMCompress polygon model compression and tolerance reduction.

[4] The following challenges were encountered and are discussed in this report:

1. ShapeGrabber calibration related alignment errors.
2. Significant holes in coverage of cockpit interior from ShapeGrabber scanning.
3. Small areas of missing and/or noisy data in the external scans.

[5] For future similar scanning projects the following is recommended:

1. More complete scan coverage of internal cockpit areas from more positions.
2. Video recording of measurement process for future use and archival information.
3. Exercising caution with ShapeGrabber orientation and calibration to avoid alignment errors in data.

[6] For future modelling call-ups the following is recommended:

1. Additional liaison with Polyworks to resolve automated hole-filling difficulty.
2. Continued and additional use and training of advanced Polyworks editing tools.
3. Continued revision and service pack updates of Polyworks and Rhino.
4. More investigation and/or use of photo-texturing for control panels and consoles.
5. On-site Internet access for technical support and access to knowledge bases.

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14. ABSTRACT

(U) This report describes the production of three graphics models of the Hercules CC130 aircraft processed from laser scan data for both the aircraft exterior and cockpit interior. These Polygon and Non-Uniform Rational B-Spline (NURBS) surface models are scalable, and logically arranged in groups and/or layers. They also represent graphically the range of motions in the cockpit of the seats and pedals.

An external mean accuracy of less than 3 millimetres (mm), and standard error of 6-9 mm for modelled areas of interest were verified with respect to the original data. An interior mean accuracy of less than 1 mm and standard error of 2-3 mm for modelled areas of interest were similarly verified. This accuracy is consistent and compatible with the accuracy of the laser scanners and their data.

(U) Le présent rapport décrit la production de trois modèles graphiques de l'avion Hercules CC130 à partir de données obtenues par lecteur laser tant pour l'extérieur de l'avion que pour l'intérieur du poste de pilotage. Ces modèles de surface polygonaux et à B-spline non rationnelle uniforme (NURBS) sont vectorisés et organisés logiquement en groupes ou couches, ou les deux. Ils représentent aussi graphiquement la gamme des déplacements des sièges et des pédales dans le poste de pilotage.

Une précision moyenne à l'extérieur inférieure à 3 millimètres (mm) et un écart-type compris entre 6 et 9 mm pour les zones modélisées dignes d'intérêt ont été vérifiés par rapport aux données d'origine. Une précision moyenne à l'intérieur inférieure au millimètre et un écart-type compris entre 2 et 3 mm pour les zones modélisées dignes d'intérêt ont fait l'objet d'une vérification similaire. Cette précision correspond à la précision des lecteurs laser et de leurs données et elle est compatible avec ceux-ci.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) 3D laser scanning, simulation and modelling, 3D modelling, CF aircraft